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Abstract

ADVANCEMENTS IN ANALYTICAL METHODS AND MACHINE COMPUTATIONS IN REACTOR PHYSICS DESIGN

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The continued improvement in reactor design is evidence of the advances made in techniques of reactor-physics analysis. These advances have been stimulated by increased knowledge of microscopic cross section data, improved numerical methods, and the availability of digital computers with more versatile capabilities. It is the purpose of this paper to review these developments and, where possible, to assess their adequacy for current design purposes.

Few-group diffusion theory has retained a dominating role in the analysis of reactors because of (1) its intrinsic simplicity, (2) wide applicability for calculating multi-dimensional neutron flux distributions, and (3) the highly developed technology for numerical solution of the group diffusion equations. With regard to the latter, there have been improvements in the now standard interative methods used for solving multi-dimensional problems. These include, for example, variational derivations of difference equations for non-orthogonal mesh coordinate systems, application of multi-line successive overrelaxation and improved alternating-direction implicit-iteration techniques, and refinements in inner-outer iteration strategy. New non-conventional concepts are being investigated for extending the scope and efficiency of group diffusion computations.

However, diffusion theory remains an approximation to the more rigorous but computationally cumbersome transport theory. The need for better approximations has stimulated the development of auxiliary artifices for gaining accuracy in treating spectral and transport effects without leaving the

simplicity of the diffusion-theory framework. More accurate representations of the thermal-energy neutron spectra, based upon detailed scattering kernels and allowing for spatial spectrum dependence, have been developed. One very useful approach involves application of variational methods to derive "overlapping thermal group" constants. Similar devices, based on variational methods, have been used to introduce other transport effects into the diffusion framework. Another major diffusion-theory limitation, the problem of homogenization both in space and energy, has received continued attention. Methods for calculating spectrum (e.g., resonances) and transport effects in relatively simple geometries have been improved.

The calculation of the lifetime behavior of a reactor is greatly complicated by the presence of control rods, voids, xenon, fission products, and other time-dependent quantities. Improved methods have been developed for "synthesizing" one- and two-dimensional distributions to obtain accurate three-dimensional distributions. These provide detailed spatial representations of complex configurations for which neutron fluxes can be readily computed. These models may be easily coupled with highly automated programs that yield group constants as a function of depletion, allowing for spectrum and self-shielding changes.

In the development of the diffusion-theory formalism discussed above, a continuing effort has been made to balance requirements for accuracy and details with the need to keep the calculational method simple and fast enough for design purposes. To assess the validity of these methods and to replace them where necessary, other techniques that essentially neglect this balance and incorporate the maximum attainable accuracy and detail must be developed. For this reason, there has been increased emphasis in numerical methods for solving higher-order approximations to the transport equation in one and higher dimensions. These include the discrete ordinates, spherical harmonics, and Monte Carlo methods, which are becoming more prevalent among the programs for evaluating transport, slowing-down, and thermal spectrum effects.